THE CTBTO/WMO ATMOSPHERIC BACKTRACKING RESPONSE SYSTEM AND THE DATA FUSION EXERCISE 2007

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ABSTRACT

Atmospheric Transport Modelling (ATM) is a Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification technology that provides the required network processing capability for measurements at radionuclide stations (particulate as well as noble gas). The associated radionuclide source location analyses are a crucial element of the treaty verification system, since they can be compared and overlaid with localization information obtained from the waveform technologies.

Based on the 2003 cooperation agreement between the CTBTO Organization (CTBTO) and the World Meteorological Organization (WMO), a WMO Executive Council decision in 2007 and an exchange of letters between the CTBTO Executive Secretary and the Secretary General of WMO, the CTBTO Provisional Technical Secretariat (PTS) can now request ATM computations from WMO Centres in near-real-time in case of anomalous radionuclide measurements. Currently, nine WMO Centres in Europe (5), North America (1), Asia (2), and Australia (1) are participating. The system serves two purposes, namely (a) to supplement and add confidence to the PTS in-house computations, and (b) to form an ensemble modeling system that accounts for the inherent uncertainty of single models and individual meteorological analyses. The system is scheduled for entry into PTS provisional operations in September 2008.

The PTS and WMO have conducted a joint atmospheric backtracking exercise in December 2007. The exercise was triggered by a seismic event from the Standard Event List (SEL3) selected according to predefined criteria, and a forward simulation of the possible release of radionuclides at this event location was performed by the event selection team to obtain a subsequent measurement scenario at IMS radionuclide sites. The evolving measurement scenario was then communicated to the PTS Monitoring and Data Analysis Section, exactly according to the timelines laid down in the Operational Manual. The PTS subsequently notified WMO Centres according to the schedules of the new response system and performed interactive source location computations. The scenario went on for 10 consecutive days, and more and more hypothetical measurement data entered the system. The source location results were overlaid with the error ellipses from seismic events, and prototype data fusion bulletins were produced and attached to the PTS Secure Web Page. The exercise was considered very successful in three respects. First, the WMO response rate was very good, given the high complexity of the measurement scenario. Second, the PTS in-house procedures for interactive radionuclide source location analysis and data fusion worked, and the developed software proved to be fit for the purpose. Third, in the final data fusion bulletin, the PTS was able to narrow down the possible source region to three seismic events that were only 150 km and 24 hours apart. This by far exceeds the possibilities of source localization analyses based on radionuclide detections only, and proves that the data fusion concept works.

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OBJECTIVES

The objectives of the CTBTO Data Fusion Exercise 2007 were to (i) test the CTBTO-WMO atmospheric backtracking response system (ensemble backward modeling), (ii) validate the source location estimation algorithm in use at the PTS, (iii) validate the PTS capability to fuse a seismic event with a radionuclide event, and (iv) test and verify new PTS procedures and possible future products related to ATM and data fusion in a real-time, realistic scenario after a nuclear explosion.

RESEARCH ACCOMPLISHED

Introduction

As part of the automated processing, the PTS calculates source-receptor sensitivity (SRS) fields for all radionuclide samples (see Wotawa et al., 2003). This is done with 14-day backward runs utilizing the Lagrangian particle diffusion model FLEXPART (Stohl et al., 1998, 2005) fed with input data from the European Centre for Medium-Range Weather Forecasts (ECMWF). The SRS fields are used for the radionuclide network processing (source location estimates). They contain geotemporal information on the sensitivity of the measurement (sample) towards releases at all points on the globe. For a more comprehensive description, see the presentation from last year (Wotawa and Becker, 2007). Similar methods can be found in the relevant literature (see, e.g., Stohl et al., 2003; Seibert and Frank, 2004).

CTBTO-WMO Response System

CTBTO/PTS and WMO have developed and tested a system where the PTS notifies WMO Regional Specialized Meteorological Centres (RSMCs) in case of anomalous radionuclide measurements. The RSMCs then send SRS fields calculated with their own models to the PTS. SRS fields are normally requested for the samples containing the relevant nuclides as well as for samples from neighbouring stations. These data supplement the PTS in-house computations. The response system has been tested and improved by means of two joint experiments in March 2003 (PTS, 2004) and January 2005 (Becker et al., 2007).

In December 2007, the PTS and the WMO conducted the third and so far most comprehensive atmospheric backtracking exercise. According to the plan, a computer model should be used to construct artificial measurements at RN stations of the International Monitoring System (IMS) after a hypothetical nuclear test. It was assumed that the final (79-station) network would already be in place. The release location would be the epicenter of a selected seismic event from the so-called Standard Event List (SEL3). The selection of the seismic event (according to predefined criteria) as well as the prediction of the related nuclear measurement scenario was to be done by a scenario selection team. The assumption was that 10^{15} Bq of a stable isotope would have been released during three hours starting from the time and location of the seismic event. The scenario selection team would then communicate the resulting hypothetical measurements to the Monitoring and Data Analysis Section of the PTS International Data Centre (IDC) exactly according to the timelines as specified in the IDC Operational Manual after Entry into Force of the treaty. The IDC would then issue “Requests for Support” to the WMO RSMCs. The RSMCs were expected to send their backtracking results to the IDC within 24 hours of each request. The IDC would then conduct its radionuclide network processing/source location analysis based on its own SRS fields and on the SRS fields contributed by the RSMCs. The IDC would try to fuse these results with the seismic event. Daily updated interactive source location and data fusion results would then be produced and attached to the IDC secure web page for access by the authorized users.

Scenario for Exercise, Notification of WMO Centres

The scenario team selected a SEL3-event that occurred on 2 December 2007 at 20:21:48 UTC at longitude 29.79°, latitude 36.57° (see Figure 1). Based on this, the ATM forward simulations were performed to construct the measurement scenario (see Figure 2). According to the computations, the first radionuclide station (RUP61) was affected on 7 December 2007. The contaminated sample would have been analyzed and finally categorized by 10 December 2007. In the following nine days, more and more anomalous radionuclide samples were predicted to be encountered at the IDC. Assuming a minimum detectable concentration (MDC) of 0.1 mBq/m^3, 77 samples would have been reported as anomalous during this time period (Table 1).

The first notification message to WMO RSMCs was sent out on 10 December 2007, and the first set of RSMC SRS fields was received by 11 December. Further notifications were issued until 19 December 2007. In total, computations were requested for as many as 102 samples (Table 1). Despite this complex scenario, the centres responded reasonably well. All but one dataset were delivered to the IDC, and 87% of the data within the predefined timelines. Most centres responded considerably faster than the 24-hour limit (see Figure 3).

PTS Source Location Analysis and Data Fusion

SRS fields can be post-processed to determine possible source locations consistent with a given measurement scenario (Wotawa et al., 2003; Becker et al., 2007), or to predict a measurement scenario for a known source scenario (Wotawa et al., 2006). As part of the PTS source location analysis, the software tries all grid cells on a global 1° x 1°/3-hour grid as sole instantaneous source and calculates all resulting measurement scenarios. These scenarios are then correlated with the real observations. Grid cells (in space and time) with high correlation values (r^2) are source locations that would be consistent with the measurements. A detailed description can be obtained from the paper presented last year (Wotawa and Becker, 2007).

During the data fusion exercise for 2007, source location analyses have been done interactively with the software package WebGrape developed by the PTS (PTS, 2005). These analyses were performed based on the PTS SRS fields as well as on the fields contributed by the WMO Centres. As new measurements came in on a daily basis, the computations were updated accordingly. The procedure for the analysis was as follows: The data fusion officer first assumed that the source acted on the first day before the first measurement of the scenario (in our case this was the 6 December 2007). Then, the analysis was repeated going back one, two, and more days. It was assumed that the source acted in a 3-hour time interval (temporal resolution of SRS fields) on the day under consideration (see Figure 4). All results were saved and displayed for subsequent overlay with the available seismic events (data fusion).

The results of the radionuclide network processing (source location) mark a relatively large area as possible source region. This is especially true if no assumptions on the source date can be made. To narrow down the area to look at, we overlay (co-display) the possible source region with known seismic events. The co-display is done in space as well as time, since we only look at seismic events occurring on the same day for which the source location analysis is valid. As can be seen, this co-display can dramatically narrow down the region under scrutiny (see Figure 5).

During the CTBTO-WMO exercise 2007, daily source location computations based on PTS SRS fields and the incoming measurement data were conducted (see Figure 6). The computed possible source regions were fused with the SEL3/Reviewed Event Bulletin (REB) seismic events. As time passed by, only three events were found to fully coincide with a correlation maximum. All these events occurred on 2 December 2007, and the preselected (ground truth) event for the exercise was one of them. During the first few days, however, the possible source regions changed considerably from day to day (Figure 6). On day 2, the ground-truth event was even outside the correlation maximum. From day 4 onward, the results remained stable, with the three events within an area of higher correlation.

WMO-Based Source Location and Fusion Results

Besides the source location results based on the PTS SRS fields, the average correlations based on the contributions from the WMO RSMCs were computed as well (see Figure 7). The three seismic events under consideration were also marked as possible source locations by this analysis, but with a substantially lower correlation. On the other hand, the WMO-based analysis remained more stable over time, and the ground-truth event was part of the possible source region also on day 2.

The differences between the results of the participating centres were investigated and compared with the results from the experiments in 2003 and 2005. In total, the statistical comparison yielded a much better agreement as seen in the years before. An arbitrary chosen case during the exercise outperformed the best case of the experiment 2005 in terms of correlation and overlap (Figure 8). This indicates the increased experience gained in backtracking over the years.

Prototype Products Produced for the Member States

Throughout the 2007 exercise, the PTS produced daily prototype data fusion bulletins for the member states and made them available through the secure web page (see Figure 9). In these bulletins, the evolving measurement scenario and the related source location results were described and discussed, and several images were made available. As part of the discussion, seismic events that were co-located with correlation maxima in space and time were identified and listed. On the last experiment day, a summary bulletin was issued. Finally, the ground truth event was one of only three events during the period of interest that were co-located with a correlation maximum. All three events were only 150 km and less than 24 hours apart (spatial and temporal difference, respectively).

CONCLUSIONS AND RECOMMENDATIONS

In December 2007, the first CTBTO-WMO Data Fusion Exercise was conducted. As ground-truth for the exercise, a SEL3 seismic event was selected, and a related radionuclide measurement scenario was computed by a scenario generation team. The measurement scenario was communicated to the PTS/IDC Monitoring and Data Analysis Section according to the timelines of the draft IDC Operational Centre. For 10 days in a row, the PTS sent out notification to WMO RSMCs to request computations of SRS fields. According to newly developed procedures, interactive source location analyses were conducted. The analyses considered PTS SRS fields as well as the SRS fields from WMO Centres. A data fusion between the source location results and the seismic events was conducted. A Data Fusion Bulletin was produced and put on the secure web page. As new measurements came in, the bulletin was updated every day. As a result, the exercise showed that the CTBTO-WMO response system works already reasonable well. It was shown once more that the source location algorithm used by the PTS does work within the constraints assumed. The PTS was able to identify three seismic events as potentially consistent with the monitoring results. These three events were only 150 km and 24 hours apart and included the ground truth event. Based on that fact, it is recommended that the response system be included in the provisional operations of the PTS as soon as possible. It is furthermore recommended that consideration be given to including data fusion in the list of products provided by the PTS to the National Data Centres of States Signatories.

DISCLAIMER

This paper reflects the views of the authors but does not necessarily reflect the views of the CTBTO Preparatory Commission.

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Table 1. Notification messages sent out during the CTBTO-WMO exercise 2007, number of detections encountered and number of SRS fields requested.

#	Request Day	Calculations requested	Detections >0.1 mBqm^{-3}
1	10-Dec-2007	5	1
2	11-Dec-2007	5	1
3	12-Dec-2007	7	3
4	13-Dec-2007	9	4
5	14-Dec-2007	8	5
6	15-Dec-2007	11	9
7	16-Dec-2007	14	11
8	17-Dec-2007	11	11
9	18-Dec-2007	16	16
10	19-Dec-2007	16	16
	SUM	**102**	**77**

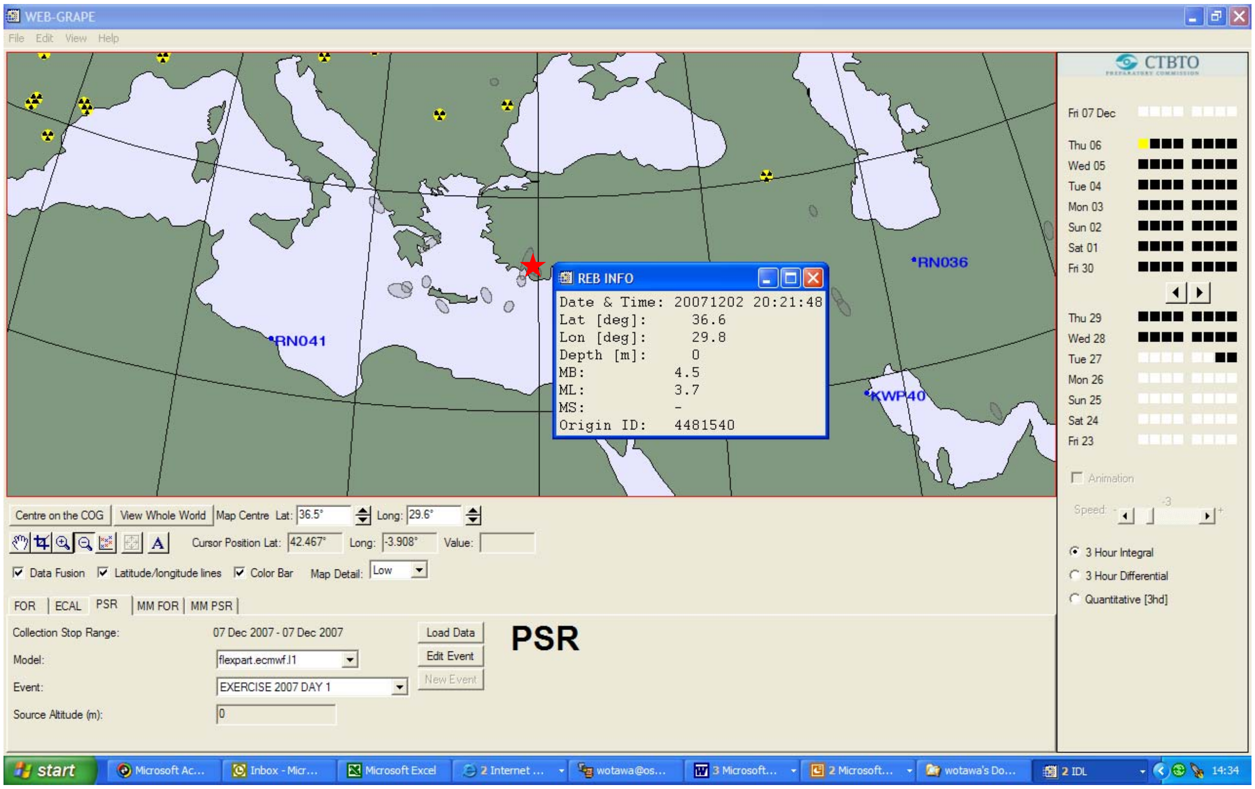


Figure 1. Seismic event from the Standard Event List (SEL3) selected for the CTBTO-WMO 2007 data fusion exercise.

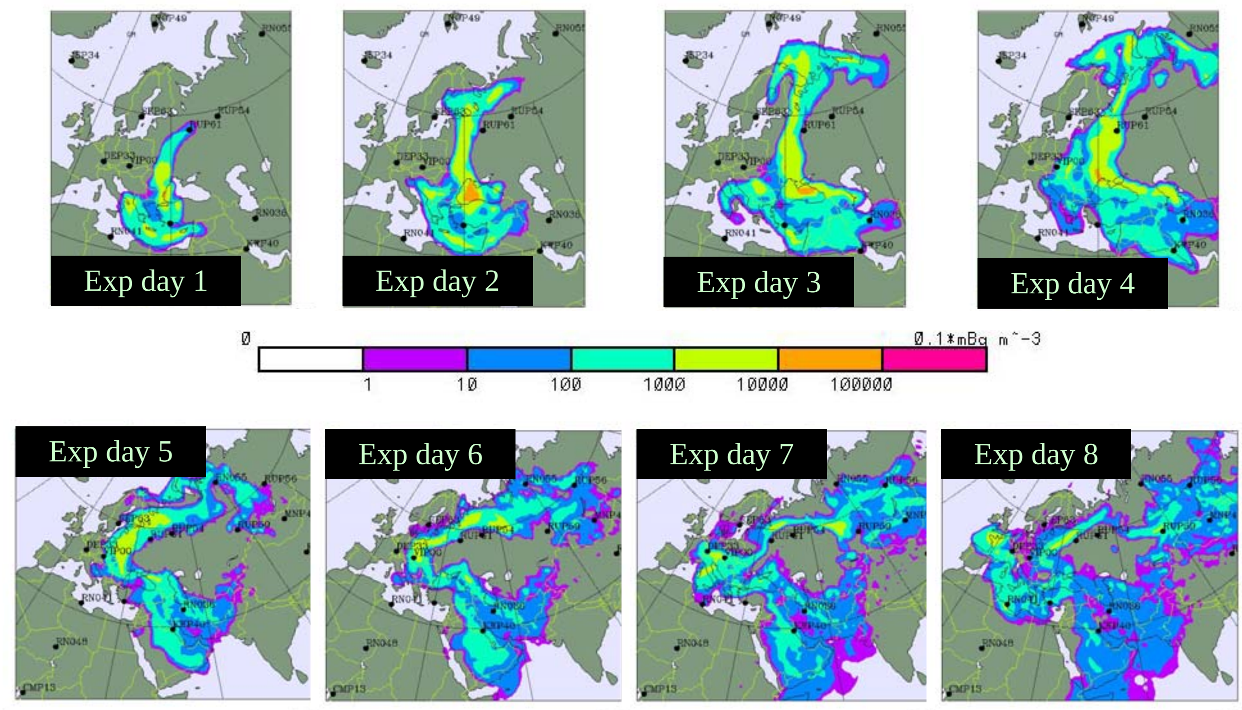
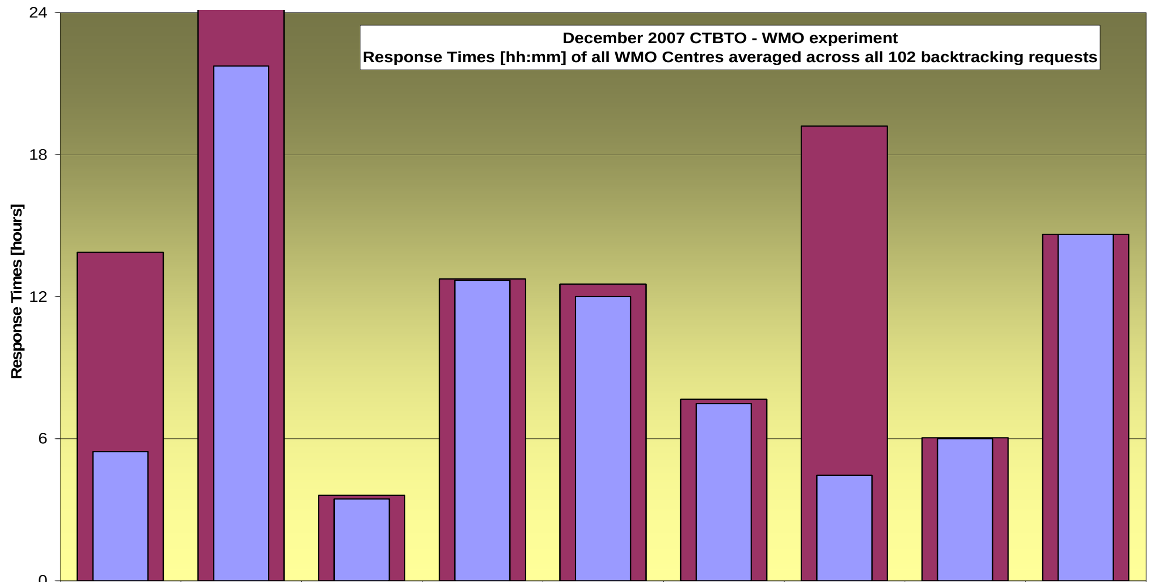


Figure 2. Radionuclide plume caused by a fictitious release of 10^{15} Bq of a stable isotope at the selected seismic event location and event time. The plume reached the first radionuclide station (RUP61) on 7 December 2007 ("Exp day 1"). On the subsequent days, more and more stations were affected.



	RSMC Washington	RSMC Obninsk	NMC Offenbach	RSMC Exeter	RSMC Beijing	RSMC Montreal	RSMC Melbourne	RSMC Toulouse	NMC Vienna
Final SRS file arrived	13:52	25:21	3:36	12:45	12:32	7:40	19:12	6:02	14:38
First SRS file arrived	5:27	21:45	3:27	12:42	12:00	7:29	4:27	6:00	14:38

Figure 3. Average response time of WMO Centres that participated at the 2007 exercise. The maximum response time foreseen was 24 hours.

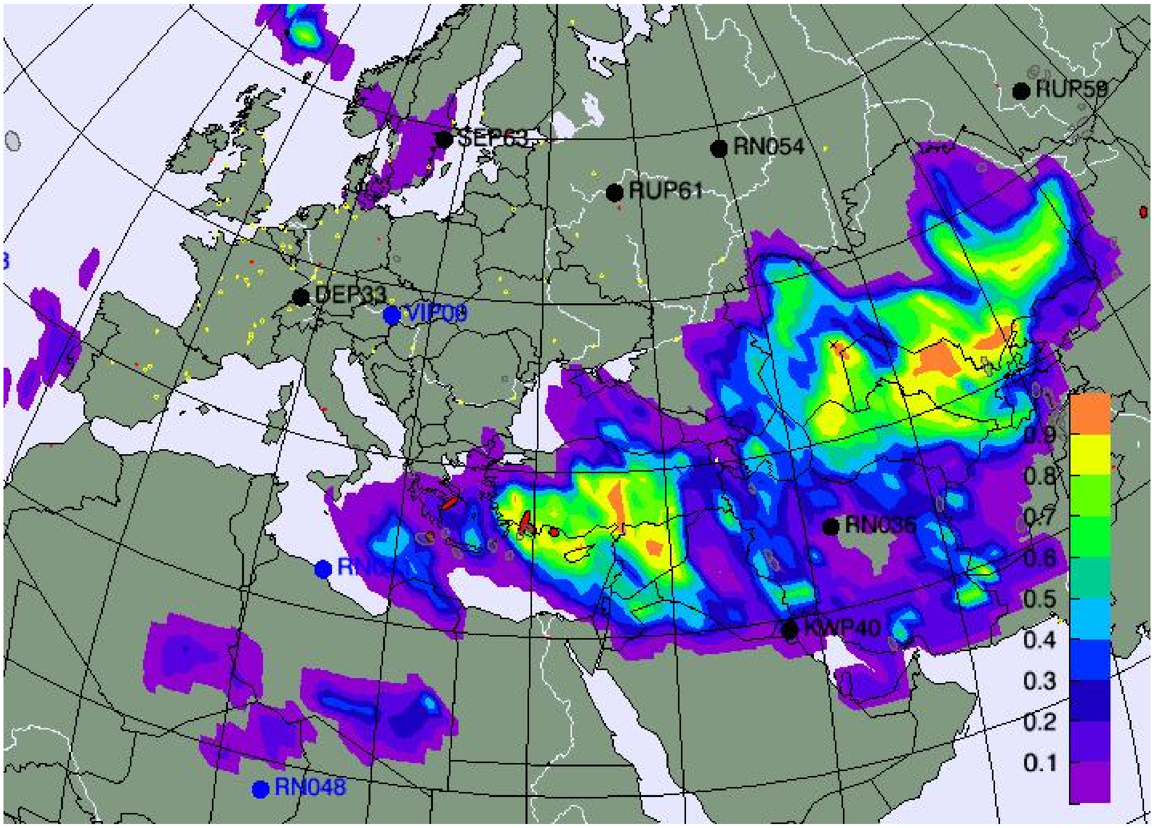


Figure 4. Display of the Possible Source Region (in terms of correlation coefficients) for the measurement scenario encountered during the CTBTO-WMO 2007 data fusion exercise (days 1–5). For this image, we assume that the source acted during one 3-hour interval on 2 December 2007.

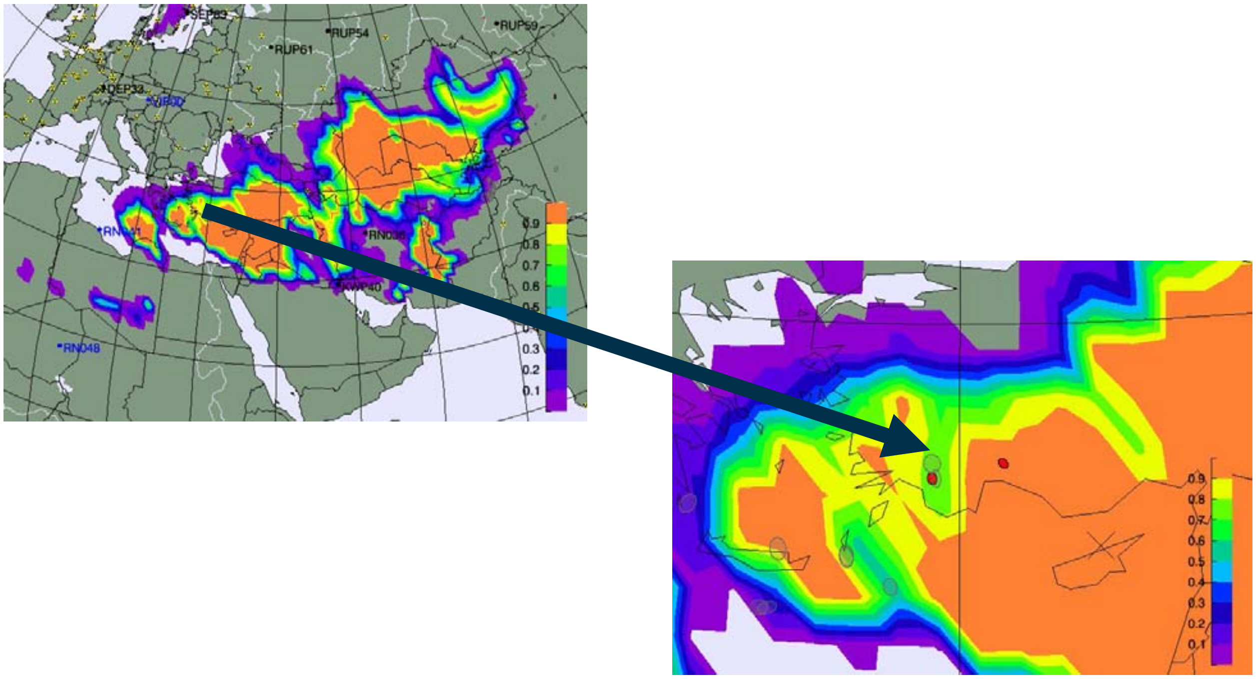


Figure 5. Principle of data fusion between radionuclide and seismic events: The possible source region from the radionuclide network processing covers a large region, while the seismic localization information, including the error ellipse, is comparatively small. The red spots on the right image mark seismic events that occurred on the same day for which the possible source region is valid. The grey spots mark events occurring on another day. The co-display of radionuclide and seismic localization information (data fusion) can dramatically narrow down the area to look at. The analysis ends up with spotting a small number of seismic events that fit in space and time.

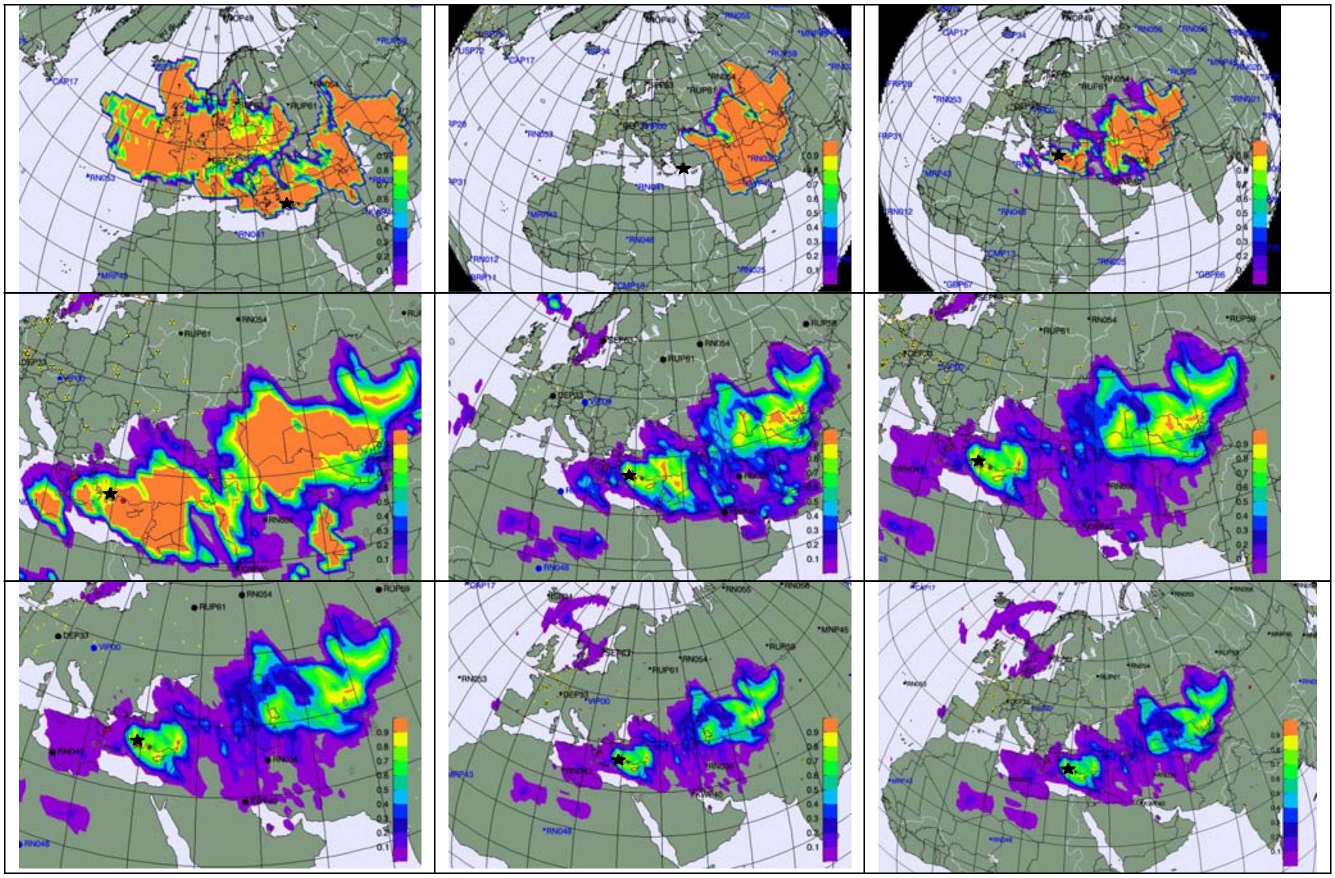


Figure 6. Data Fusion results based on the PTS SRS data during the first nine days of the CTBTO-WMO exercise 2007 (from top left to bottom right). Results changed significantly for the first four days, based on the new measurements coming in, while staying stable from day 5 onwards. The ground truth location is marked black.

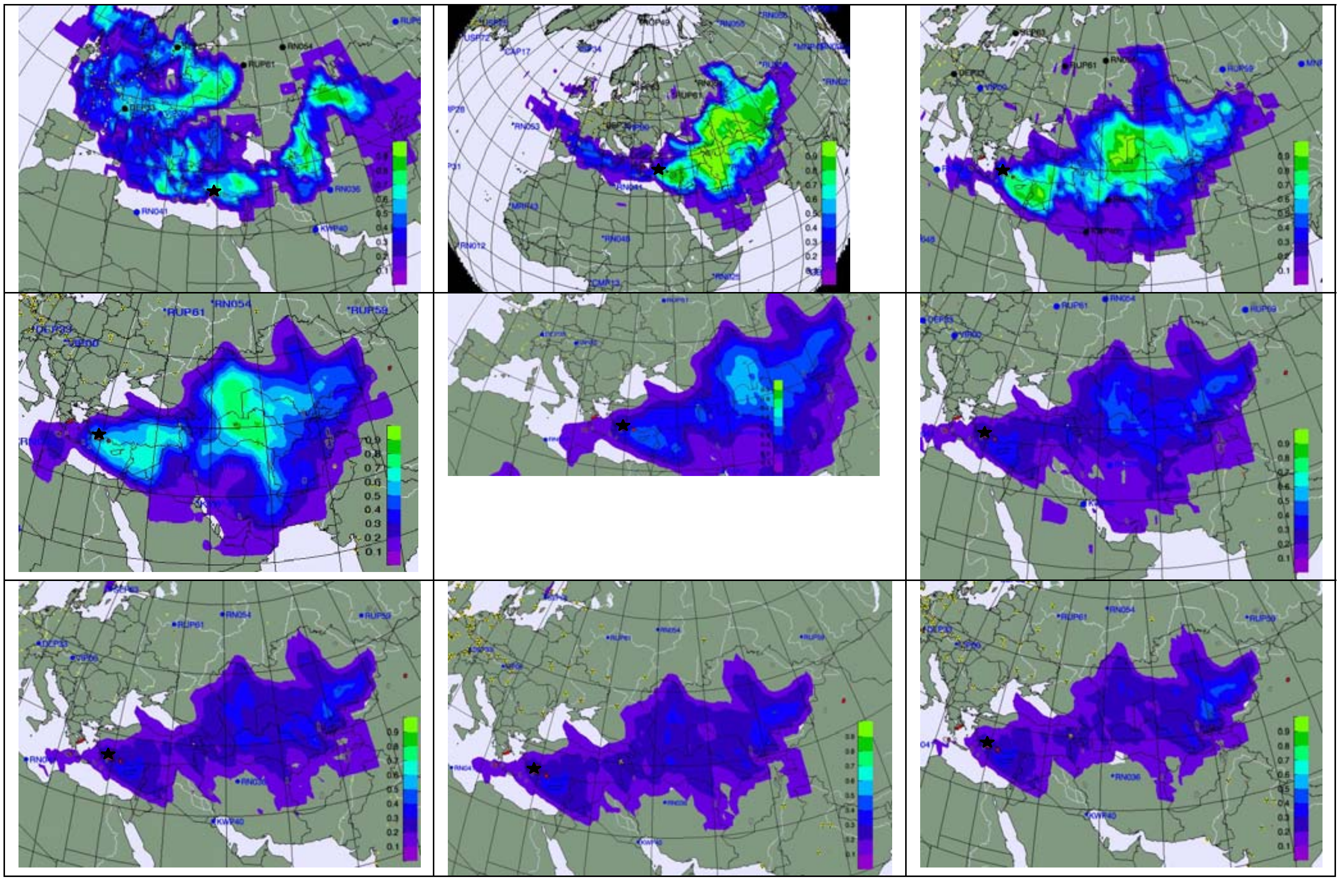
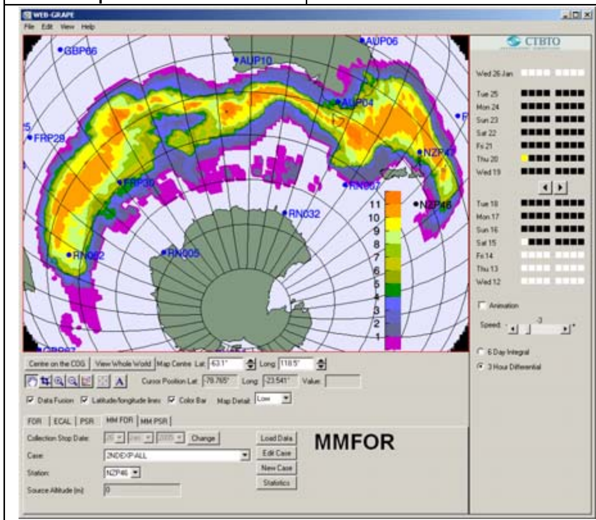


Figure 7. Data fusion results based on the WMO SRS data (multimodel average correlation results) during the first 9 days of the CTBTO-WMO 2007 exercise (from top left to bottom right). Results changed for the first 3 days based on the new measurements coming in, while staying stable from day 4 onwards. The ground truth location is marked black.

Best congruent case in 2005		An average case in 2007 (1st detection of predicted scenario)	
RN Station Sample Overall Agreement / Overlap	NZP46; 26 January 2005; 6 UTC 50.90% / 42.11%	RN Station Sample Overall Agreement / Overlap	RUP61; 07 December 2007; 06 UTC 54.19% / 50.01%



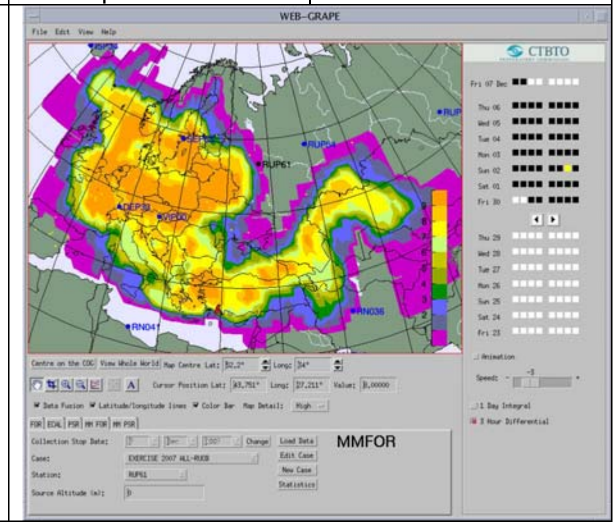
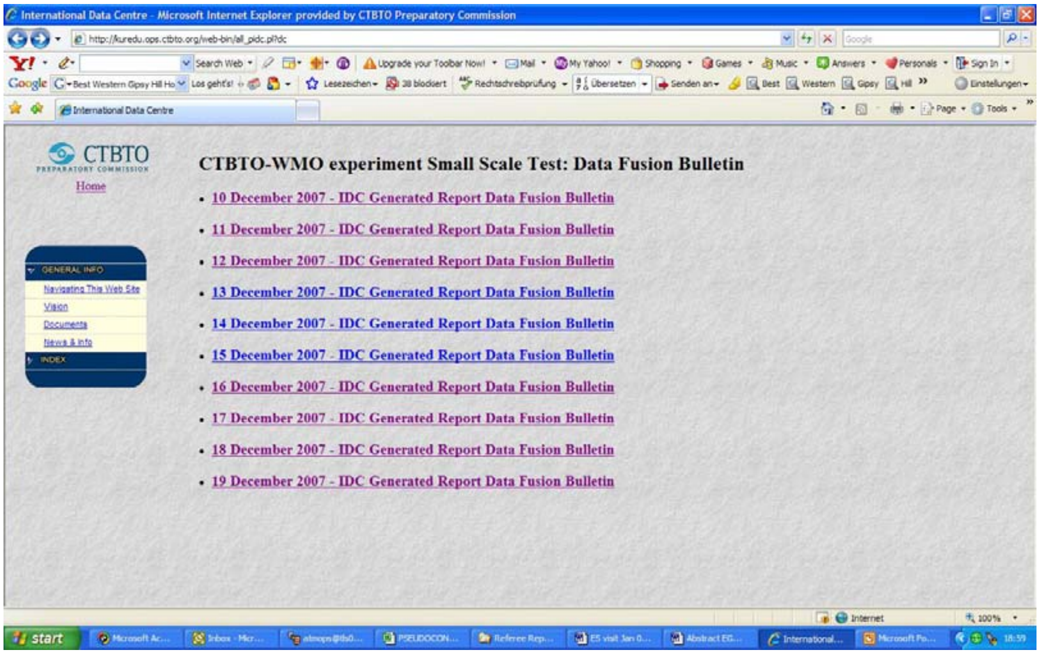


Figure 8. Model agreement, January 2005 vs. December 2007 experiment. Comparison of the WMO centres overlap (Figure of Merit in Space) during January 2005 and December 2007 experiments. The left box shows the best congruent case of the 55 samples examined in January 2005 (Becker et al., 2007). The right box shows an arbitrarily chosen case with regard to the 102 backtracking requests examined during the December 2007 experiment. It is noticeable that this case outperforms the best case of January 2005 in terms of model agreement and overlap visualized for the three hours indicated in the calendar of the PTS post-processing software *WEB-GRAPE*.



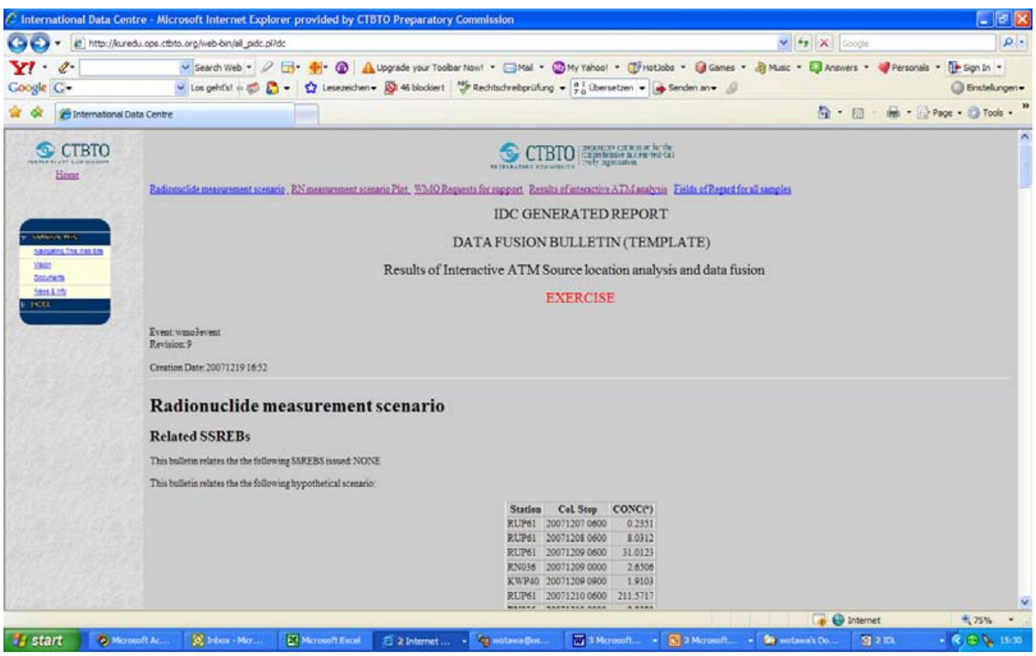


Figure 9. A daily data fusion bulletin was issued by the PTS on its secure web page during the CTBTO-WMO 2007 Exercise (top). Every bulletin contained a description of the measurement scenario plus the related source location and data fusion results (bottom).